

Geology, Climate, and Landscape of the PABITRA Wet-Zone Transect, Viti Levu Island, Fiji¹

Roselyn Kumar²

Abstract: The PABITRA Gateway Transect in Fiji covers most of the eastern part of Viti Levu, the largest island in the archipelago. Viti Levu is located exclusively on the Fiji Plate, a microplate between the giant Pacific Plate and the Indo-Australian Plate that has been moved counterclockwise within the past 42 million yr as a result of their oblique convergence. There is no secure geologic evidence that Viti Levu was ever in contact with part of Gondwana, despite the presence of Gondwana flora. The oldest rock series in the area is the submarine Eocene Wainimala Group, intruded in places by the Colo Plutonics. These are succeeded by the Medrausucu Andesitic Group, the Ba Volcanics, and the Verata Sedimentary Group, a Plio-Pleistocene group of sediments representing deltaic and shallow-water deposition in the southeast of the area. The modern Rewa Delta and associated alluvial flats compose the youngest rocks in the area. The geology of the six study sites within the PABITRA Transect is explained in detail. Being on the windward side of the island, the area's climate is humid tropical, with the lowest temperatures and highest precipitation being associated with the highest elevations. A short account of the area's landscape is given.

THE PABITRA PROJECT is intended to highlight the current state of biodiversity in key areas across the Pacific. The area on which this paper focuses is eastern Viti Levu Island in the Fiji Archipelago, Southwest Pacific Ocean. This paper gives the physical background for the biogeographic studies that follow. It deals first with the geology of the Fiji PABITRA Gateway Transect, being particularly concerned with the question of whether Viti Levu Island is wholly oceanic or whether it contains or was ever in direct contact with elements of the Mesozoic supercontinent Gondwana. Second, it considers the climate of the PABITRA Gateway Transect and the climatic variations that help ex-

plain its biogeography. Finally it considers the landscape of the PABITRA Gateway Transect and the processes that operate to change this landscape.

The Fiji Archipelago comprises some 350 islands, of which around 90 are inhabited, permanently or temporarily (Figure 1). There is considerable variation, from the elongate, intensely folded Yasawa Islands in the west through the young volcanic islands Kadavu, Koro, and Taveuni to the high limestone islands of the Lau group in the east. The smaller islands of the group generally cluster around the two largest, Viti Levu and Vanua Levu, which have, not surprisingly, the oldest rocks and the most complex geologic histories.

The PABITRA Gateway Transect occupies most of the eastern half of Viti Levu Island, at 10,388 km² the largest in the Fiji group (Figure 2). Most of the PABITRA Gateway Transect, within which six constituent study areas have been recognized, lies within the Rewa River catchment and involves around 1,320 m of relative relief (Figure 3). This island occupies a minor

¹ Manuscript accepted 15 April 2004.

² Institute of Applied Sciences, The University of the South Pacific, Suva, Fiji.

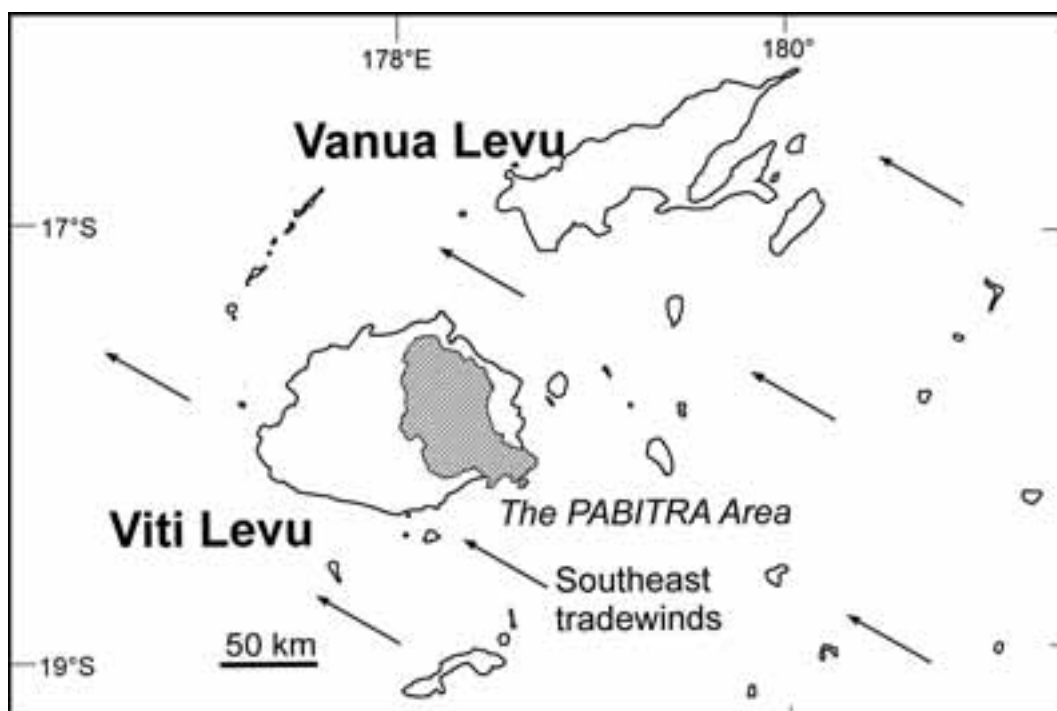


FIGURE 1. Location of Viti Levu Island within the Fiji Archipelago. Arrows show the dominant southeast tradewinds.

lithospheric plate named the Fiji Plate that comprises a core of Eocene rocks named the Wainimala Group. Since its formation, Viti Levu has undergone folding and uplift associated with the movements of the giant Pacific and Indo-Australian Plates. Fiji has been a center of island-arc volcanism, providing environments for deltaic sedimentation at periods of Quaternary high sea levels. These are now preserved as aprons of sedimentary rock fringing the island's igneous interior. The climate of Viti Levu shows a sharp contrast between the wetter southeast and east sides and the drier west and northeast sides, a contrast explicable by the dominance of moist tradewinds from the southeast. The island's landscape shows variations that can be explained largely by geology and climate although there is some discussion as to how much such variation is also due to human impact. These are some of the issues highlighted in the sections that follow.

GEOLOGIC EVOLUTION OF VITI LEVU ISLAND

The oldest rocks on Viti Levu Island demonstrate that it once formed part of the now-defunct Vitiaz Arc, a plate-convergence zone that was active more than 42 Ma between the Pacific and Indo-Australian Plates. The linear Vitiaz Arc extended from the Solomon Islands to the Tongan island of 'Eua and became disrupted and then abandoned as a result of a change in the direction of Pacific Plate motion about 42 Ma. Since that time, the Fiji Plate (and the island of Viti Levu) have been rotating counterclockwise (Colley and Hindle 1984, Inokuchi et al. 1992, Rodda 1994).

It has been suggested that, because there are unmistakable elements of Gondwanan floras on Viti Levu today, these must have reached the island either when it was once part of Gondwana or when it was in contact

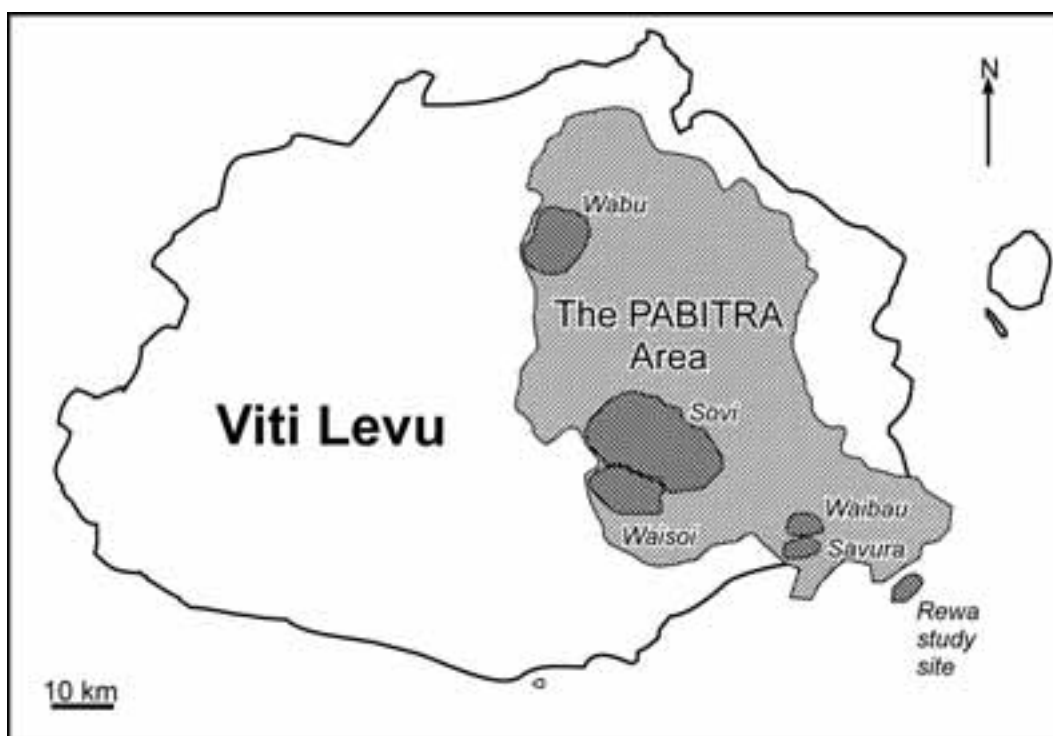


FIGURE 2. Viti Levu Island showing the location of the PABITRA Gateway Transect and its six constituent study areas.

with Gondwana. There is no geologic evidence known from modern Viti Levu Island to support the idea that it was ever part of Gondwana. Although some early writers were convinced, largely because of its size and apparent geologic complexity, that Viti Levu was a continental fragment, work by Gill (1976) and others on the nature of oceanic volcanism did not support the continental fragment hypothesis. All of the rock formations found on Viti Levu are commonly produced by processes of oceanic volcanism. Furthermore, none of the rocks on the island are likely to be more than about 40 million yr old, whereas Gondwana was in existence more than 200 Ma.

In a plate-tectonic reconstruction model of the Southwest Pacific from 0 to 100 Ma, Yan and Kroenke (1993) showed that about 41 Ma part of the Norfolk Ridge (a Gondwanan fragment that includes modern New

Caledonia) apparently slewed off and moved eastward into the South Fiji Basin, driven by sea-floor spreading in the Loyalty Basin. This fragment of Gondwana eventually became incorporated into the Tongan Arc as the island 'Eua about 20 Ma. It is possible that during its transit of the South Fiji Basin this Gondwana fragment came close enough to the nascent Viti Levu Island to transfer some of its distinct flora. This scenario was not suggested explicitly by Yan and Kroenke (1993) but by Mueller-Dombois and Fosberg (1998). During the Quaternary period, Viti Levu continued to be uplifted as a consequence of the effects of the oblique convergence of the Pacific and Indo-Australian Plates on the Fiji Plate. This uplift is expressed within the PABITRA Gateway Transect as deeply incised valleys (such as that of the Wainimala) in the island's interior and a host of other features described by Nunn (1998). The evidence

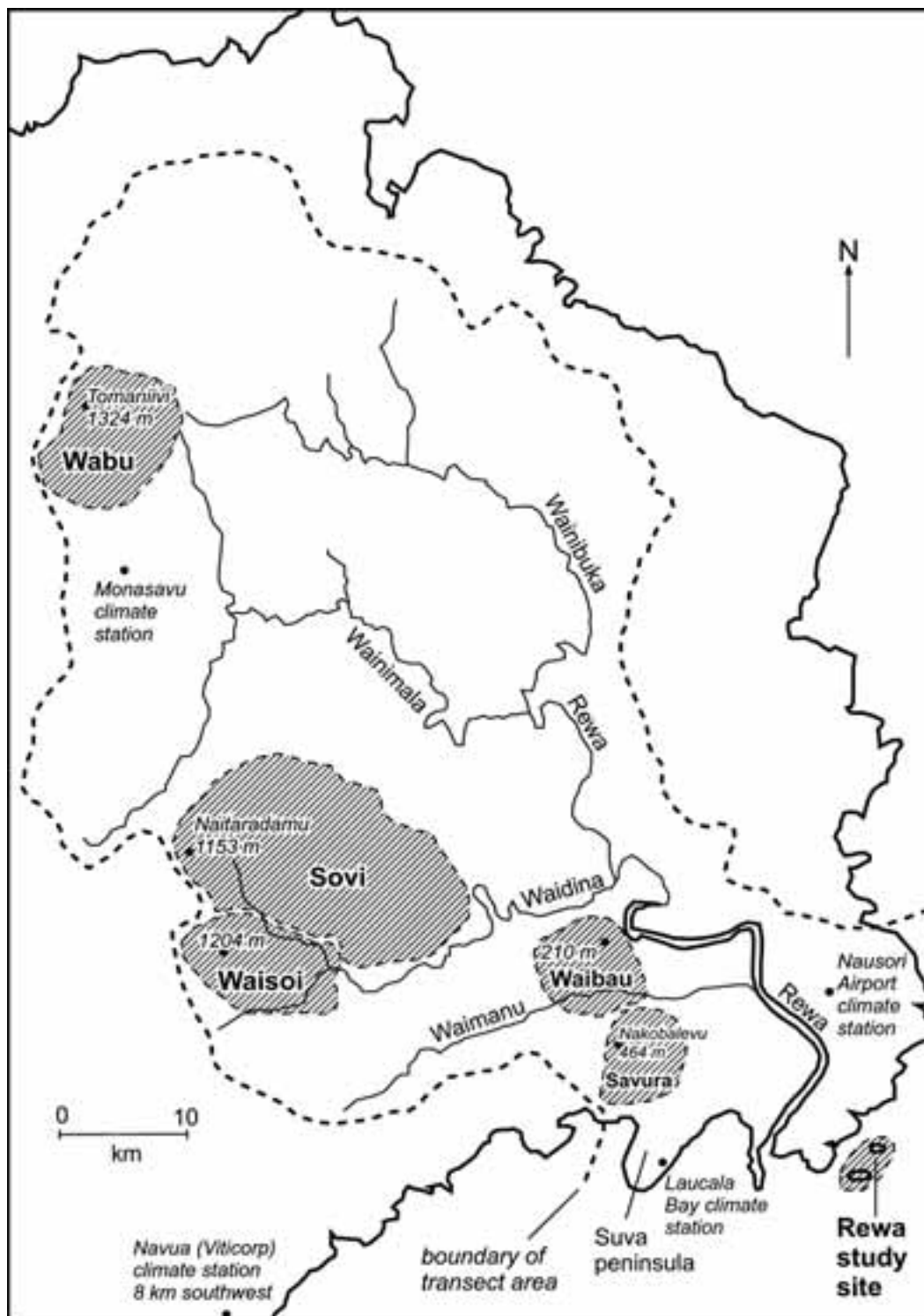


FIGURE 3. Outline of the drainage and topography of the PABITRA Gateway Transect. The locations of the climate stations discussed in the text are also shown.

for Quaternary uplift is also well marked along some of the island's coast. A range of emerged coral reefs and erosional benches is found (Nunn 1998). A synthesis of the evidence for a Holocene high sea level around the island concluded, as for the rest of the archipelago, that sea level reached about 1.5–2.1 m above its current mean level along the south coast about 4,000 years B.P. For the north coast of Viti Levu, the evidence is consistent with subsidence of 0.2 mm^{-1} since at least 6,000 years B.P., probably associated with tectonic downwarping of the shallow offshore shelf (Nunn and Peltier 2001).

GEOLOGY OF THE PABITRA GATEWAY TRANSECT

Overview: Major Chronostratigraphic Units

The oldest rocks in the PABITRA Gateway Transect (Figure 4) belong to the Wainimala Group, a series of submarine or shallow-water deposited formations including volcanic and sedimentary facies. The origins of the Wainimala Group are poorly understood, but they occupy a conspicuous basement throughout the island of Viti Levu dating from 40 to 30 Ma (Whelan et al. 1985). It seems clear that they were originally laid down horizontally but have subsequently been folded and uplifted. Within the PABITRA Gateway Transect, the Wainimala Group rocks are exposed in a band east-west across its center. Good exposures of Wainimala Group rocks here are found along the banks of the deeply incised Wainimala River, described by Rodda (1976).

A series of plutonic rocks (the Colo or Tholo Plutonics) were intruded in the upfolds of the Wainimala Group during an event known locally as the Colo Orogeny (Rodda 1994). Within the PABITRA Gateway Transect, the Colo Plutonics occur in three principal areas. The northernmost is an elongate outcrop forming a deeply weathered ridge, followed by the road between Naitauvoli and Lutu (Wainimala). The largest of the exposed batholiths is that which occupies most of the Sovi study area (see discussion of that area). The landscape it forms

is irregular, reflecting the irregular form of the original intrusion and the considerable surface lowering that must have taken place since intrusion occurred some 12 Ma. It is estimated that between 10 and 15 km of overlying material have been removed from above the Colo Plutonics in this area. As elsewhere on Viti Levu, hot springs are associated with the Colo Plutonics in the south-central part of the PABITRA Gateway Transect, particularly along the Waidina Valley, signaling the presence of geothermal anomalies there (Nunn 1998).

The Medrausucu (Mendrausuthu) Andesitic Group overlies the Wainimala Group rocks in the south of the PABITRA Gateway Transect, extending from the Wainimala Valley near Naivucini Village to the coast. They form an impressive fault scarp extending approximately north-south in the central part of the area. Many waterfalls tumbling over the edge of the scarp suggest that it may still be rising, with the rivers having insufficient time to grade themselves across the scarp. The Sovi River exits the Sovi Plateau just behind this scarp and some good sections of the andesitic series are visible there.

A series of unclassified intrusive igneous rocks are found in places throughout the transect area and appear to fall stratigraphically between the Medrausucu Andesitic Group and the Ba Volcanic Group.

The Ba (Mba) Volcanic Group outcrops throughout the northern part of the PABITRA Gateway Transect. It is the youngest igneous formation therein. These extrusive igneous rocks are the products of north-coast volcanoes that were active during the Tertiary (Rodda 1994). The voluminous lavas and other volcanic products infilled much of the preexisting topography and account for the modern low-relief surface in the highest parts of the PABITRA Gateway Transect (the Nadrau and Rairaimatuku Plateaus). It is also noted that a small volcano, classified on the basis of age and lithology as Ba Volcanic Group, is exposed at Nakobalevu in the southern part of the PABITRA Gateway Transect (Bonato 1997).

The Verata Sedimentary Group is composed of shallow-water marine and deltaic

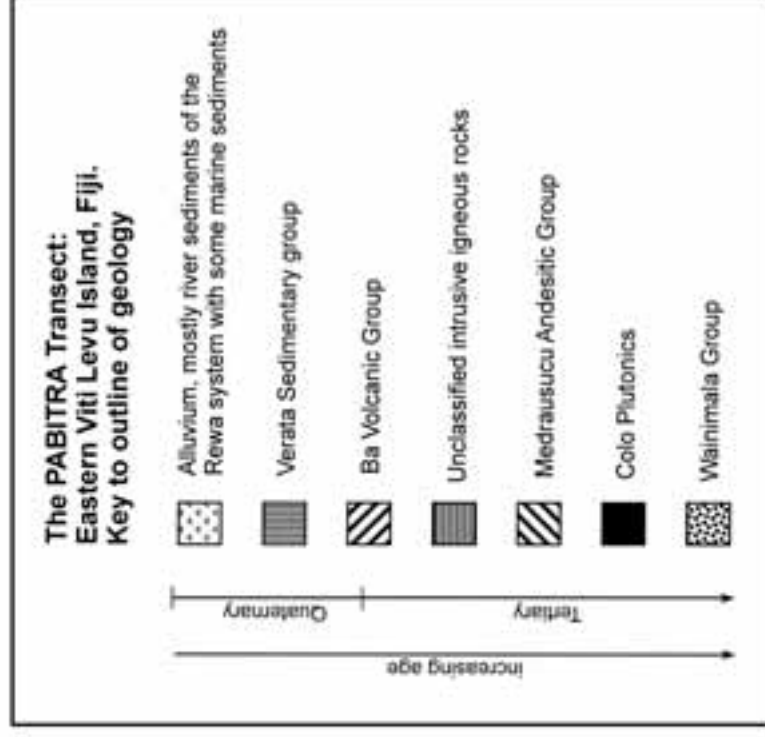
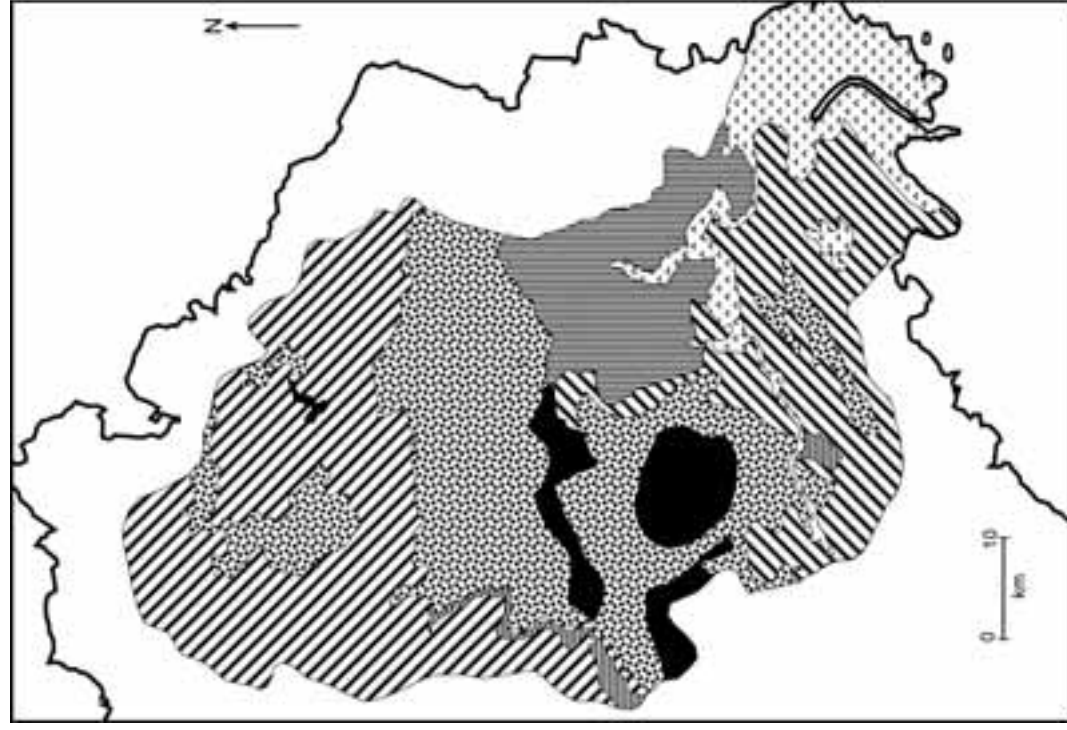


FIGURE 4. The geology of the PABITRA Gateway Transect (see text for details).

facies and is found throughout the central-eastern part of the PABITRA Gateway Transect. In simple terms, the outcrop of the Verata Sedimentary Group can be seen as an ancient delta of the Rewa River. The topography is undulating, in part due to the compressional folding and uplift that has affected these sediments since they were lithified. Excellent sections are occasionally seen when banks collapse along the gorge section of the Rewa channel north of Baulevu. The outlier named Nacau just north of Naivucini Village is another impressive exposure and is bisected by the Waiqa Gorge.

The modern delta of the Rewa River and associated alluvial lowlands are the youngest chronostratigraphic unit in the PABITRA Gateway Transect. Comparatively little is known about lithologic variations within this unit but most appear to be of sand and silt grade material with occasional gravel ridges of coral rubble accreted along the delta front and large amounts of clay beneath the surface in the delta proper. There are several islands of deltaic material off the delta front that appear to have once been part of the mainland but had their connection severed during large floods. Other islands such as Nasoata and Valolo appear to be made at least in part from marine (reef-derived) materials thrown onshore during storms.

INDIVIDUAL STUDY AREAS

The PABITRA Gateway Transect contains six sites of particular biogeographic interest (see Figures 2 and 3). For this reason, their geology is described in more detail here.

The Wabu Study Area

The Wabu study area comprises rocks that belong exclusively to the Ba Volcanic Group (Figure 5). The oldest are undifferentiated, mostly basalt flows, which are exposed in the south-central part of this area. Next oldest are the sandstones of the Vatuoro Greywacke and youngest are the conglomerates of the Nakorotubu Basalt, which are exposed in the northern part of the study area.

The Sovi Study Area

The Wainimala Group is represented within the Sovi study area (Figure 6) by the Nubuo-naboto Volcanic Conglomerate. It encircles the main outcrop of Colo Plutonics in the area. There is also an outcrop of Colo Plutonics in the west of the area. The Medrausucu Andesitic Group is found in the east of the area, represented by the Namosi Andesite, which forms towering cliffs along the north bank of the Waidina River here. Along the Sovi Gorge in the east of the study area, sections of Namosi Andesite capping a basement of Nubuo-naboto Volcanic Conglomerate can be seen. As in Wabu (see preceding discussion on that area), many sections in this area have been exposed following mass movements along the flanks of the steep-sided valleys, but vegetation rapidly obscures fresh exposures of this kind.

The Waisoi Study Area

The Nubuo-naboto Volcanic Conglomerate and Namosi Andesite (see preceding section) also dominate the Waisoi study area (Figure 7). The older rocks generally form more subdued terrain, and the Namosi Andesite forms high cliffs often sparsely vegetated because of frequent rock falls. The alluvium of the Waidina Valley (west to east flowing) is an important component of this area.

The Waibau Study Area

The oldest rocks in the Waibau study area (Figure 8) belong to the Wainimala Group and are a group of fine ash deposits named the Tawavatu Tuff. The next youngest rocks belong to the Medrausucu Andesitic Group and are named the Vago Volcanics; in the study area they comprise andesite flows and pyroclastics. The Ba Volcanic Group is represented here by the Nakobalevu Basalt (see earlier discussion), which is distinctive because of its greenish color given by olivine minerals. The Verata Sedimentary Group is here represented by the Waidina Sandstone. Alluvium of the Rewa River system is exposed in the northeast of the area.

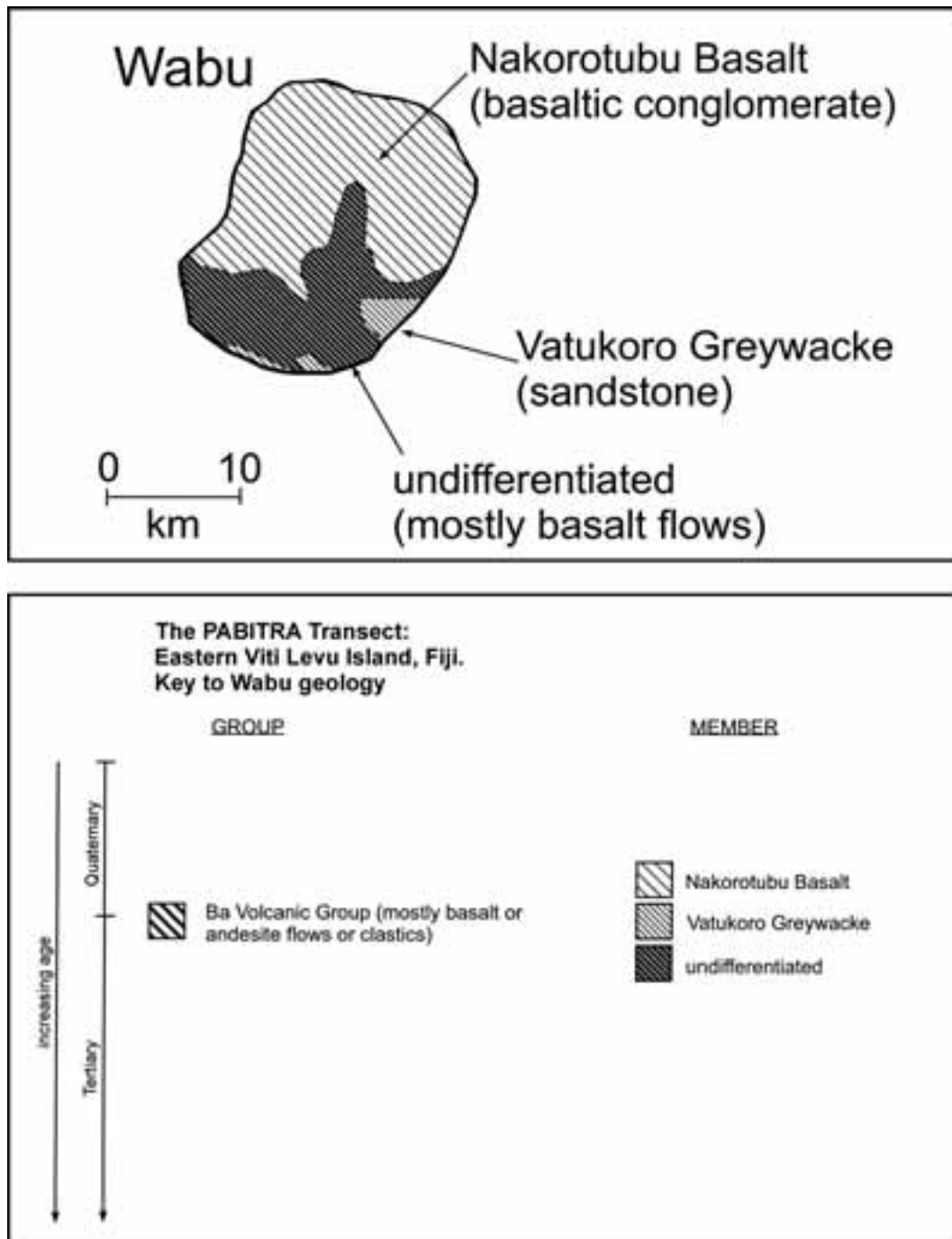


FIGURE 5. The geology of the Wabu study area (see text for details).

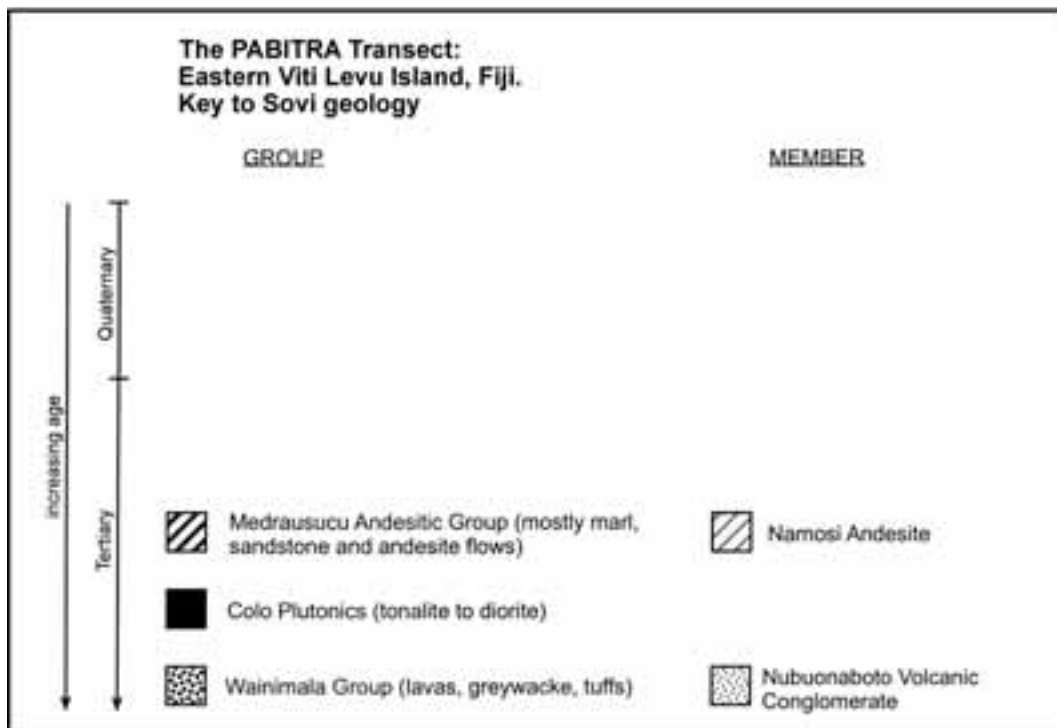
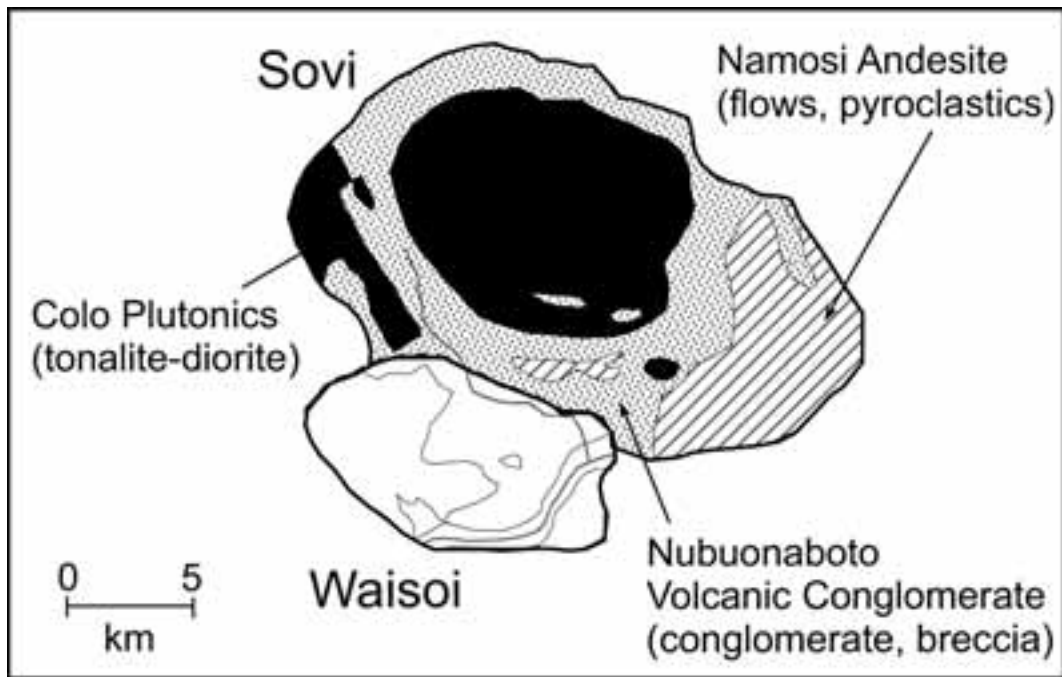


FIGURE 6. The geology of the Sovi study area (see text for details).

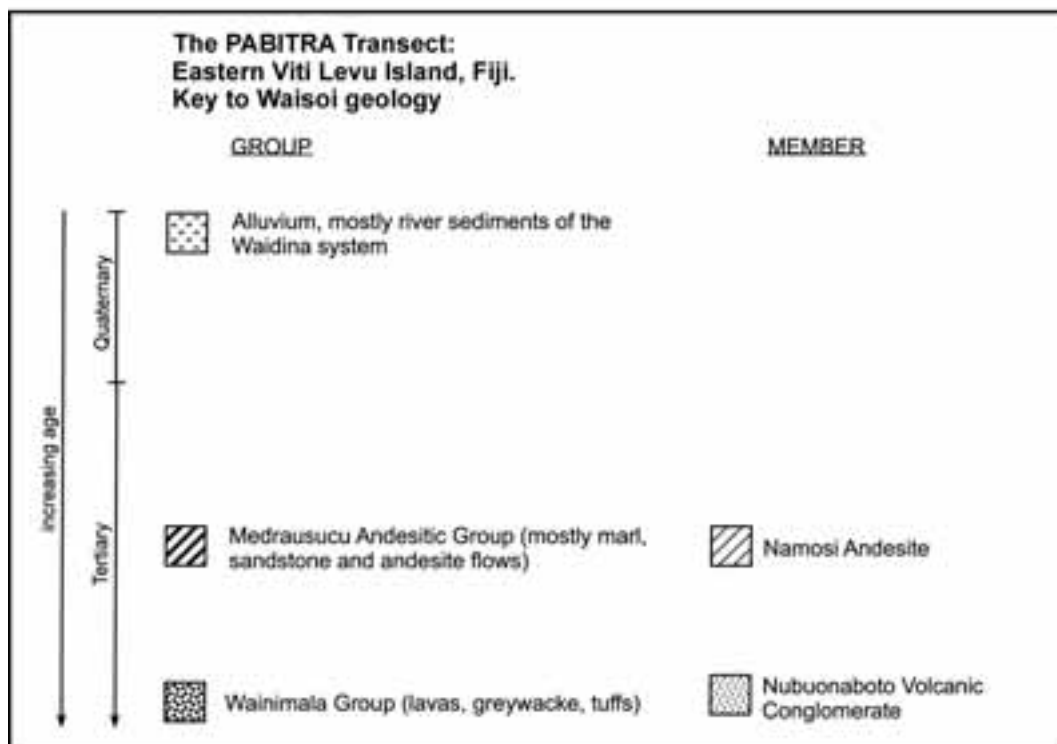
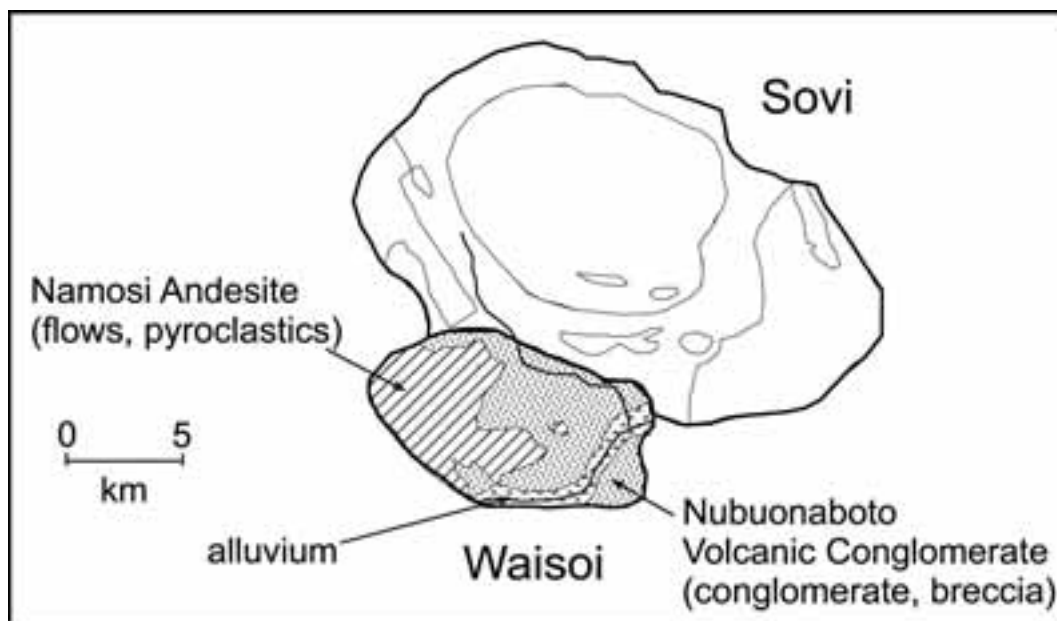


FIGURE 7. The geology of the Waisoi study area (see text for details).

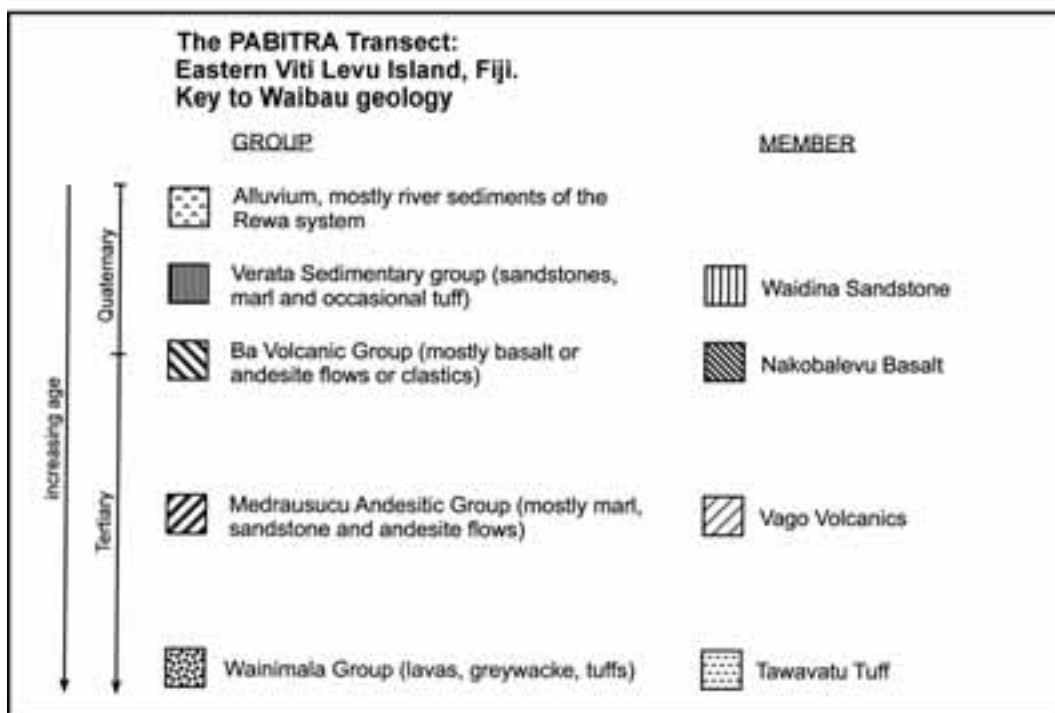
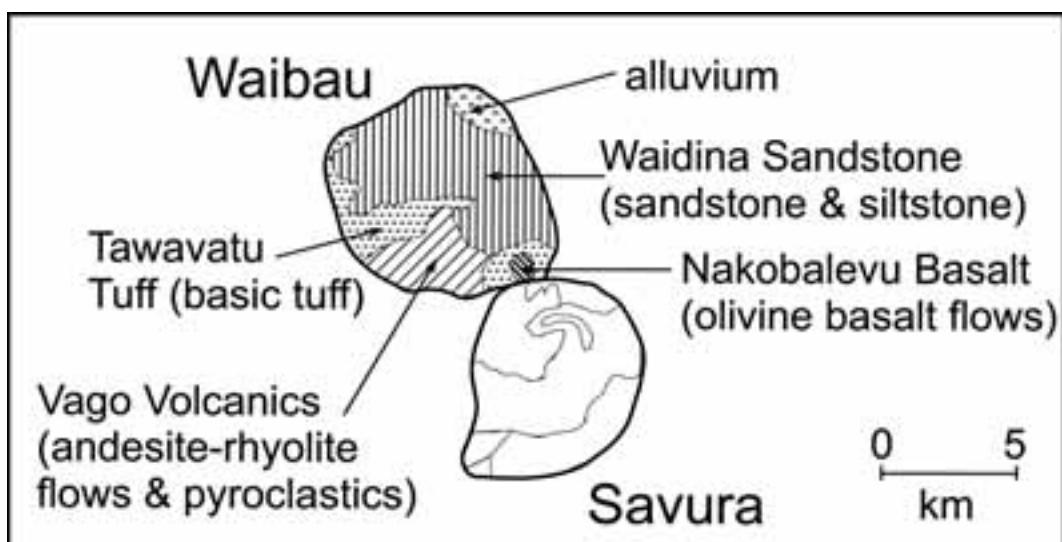


FIGURE 8. The geology of the Waibau study area (see text for details).

The Savura Study Area

The geology of the Savura study area (Figure 9) is similar to that of the Waibau study area, with the Tawavatu Tuff (Wainimala Group), the Vago Volcanics (Medrausucu Andesitic Group), and the Nakobalevu Basalt (Ba Volcanic Group) being present here along with river alluvium. What is different in this area is the presence of two additional members of the Medrausucu Andesitic Group, both younger than the Vago Volcanics. These are the Veisari Sandstone and the Suva Marl, emerged deltaic sediments found in the southeast of the study area.

The Rewa Study Area

The Rewa study area comprises the two islands Valolo and Nasoata offshore the edge of the modern Rewa Delta (Figure 10). Both islands are composed solely of alluvial-type material, although with substantial amounts of marine-derived sediment (such as reef fragments) and marine-transported material (such as pumice) in places.

CLIMATE OF FIJI

The climate of Fiji is maritime, dominated by the effects of the southeast tradewinds in establishing wet cooler windward parts and dry warmer leeward parts (see Figure 1). Annual precipitation on the windward side of Viti Levu Island is generally 3,000–4,000 mm, but on the leeward side it is commonly less than half that amount.

Superimposed on this general picture are the effects of tropical cyclones (hurricanes), which affect the country about once every 2 yr on average. These generally approach Fiji from the ocean “hot spot” in the Solomon Islands (from the northwest) and therefore often disproportionately affect the leeward side of the group. Huge amounts of rainfall may fall during the passage of a tropical cyclone; the high winds often cause substantial damage. The El Niño phenomenon brings droughts to Fiji, on average currently every 4–7 yr. There is evidence that temperatures

in Fiji have been increasing over the past few decades, and the frequency of tropical cyclones also has been increasing (Nunn et al. 1999).

Climate Variations within the PABITRA Gateway Transect

The PABITRA Gateway Transect lies largely within the wet windward side of Viti Levu; only some of its northern and western margins might be considered transitional between windward and leeward. Four climate stations have been selected to characterize the variations of climate within the PABITRA Gateway Transect (see Figure 3).

The inland part of the PABITRA Gateway Transect (including the study areas of Wabu, Sovi, and Waisoi) is characterized by the Monasavu climate record (Figure 11A). This involves 22 yr of data records, a mean annual temperature of 20.3°C, and a mean annual precipitation of 4,928 mm. The cool temperatures pertain all year round and account for the cloud forest found here and in the Wabu study area. Temperatures are warmer in Sovi and Waisoi, where elevations are lower. The high levels of precipitation here, concentrated in summer (December to February) when they are supplemented by rain from tropical cyclones, are typical of all three study areas, in which dense forest growing in deep regolith points to such climate probably having prevailed for much of the past 10,000 yr or so. Had wet conditions come to dominate this area only recently it seems unlikely that regoliths 30 m or more in thickness could have formed (Nunn 1998).

The western part of the southern PABITRA Gateway Transect is represented by the Navua (Viticorp) climate station (Figure 11C), where again there are 22 yr of data. The mean annual temperature of 24.5°C is representative of the coastal strip here but undoubtedly falls as one progresses inland and upward. The mean annual precipitation of 3,468 mm is exceedingly high for coastal locations on Viti Levu Island. Here the southeast tradewinds hit the island most consistently and most strongly. Precipitation levels may not change substantially inland

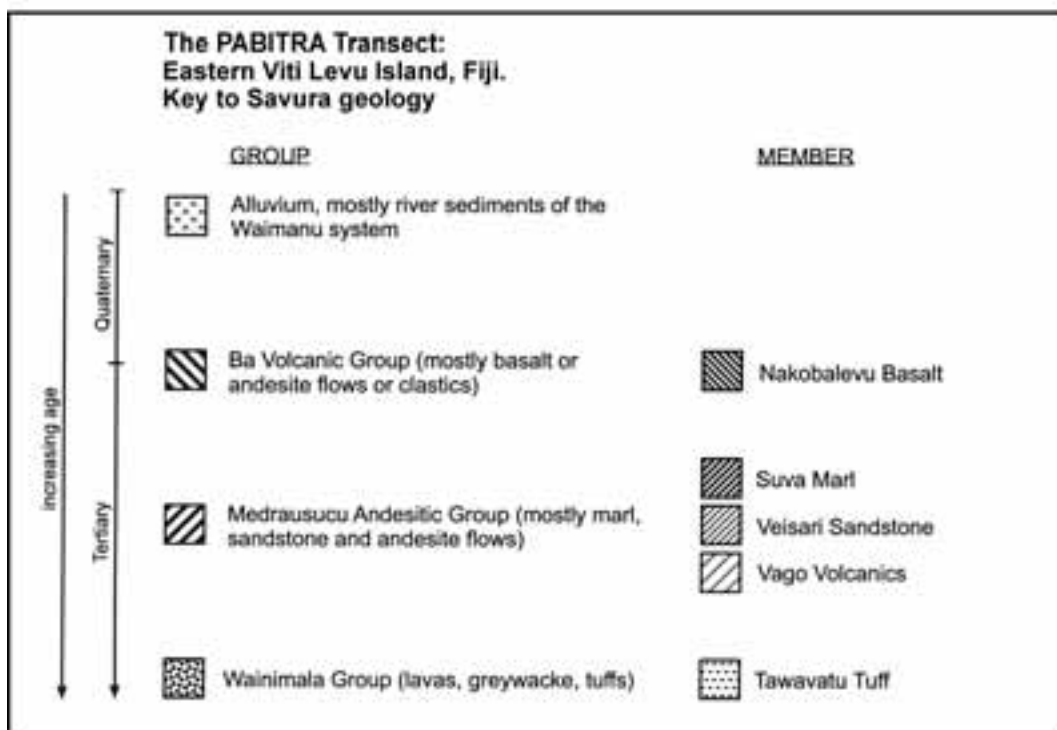
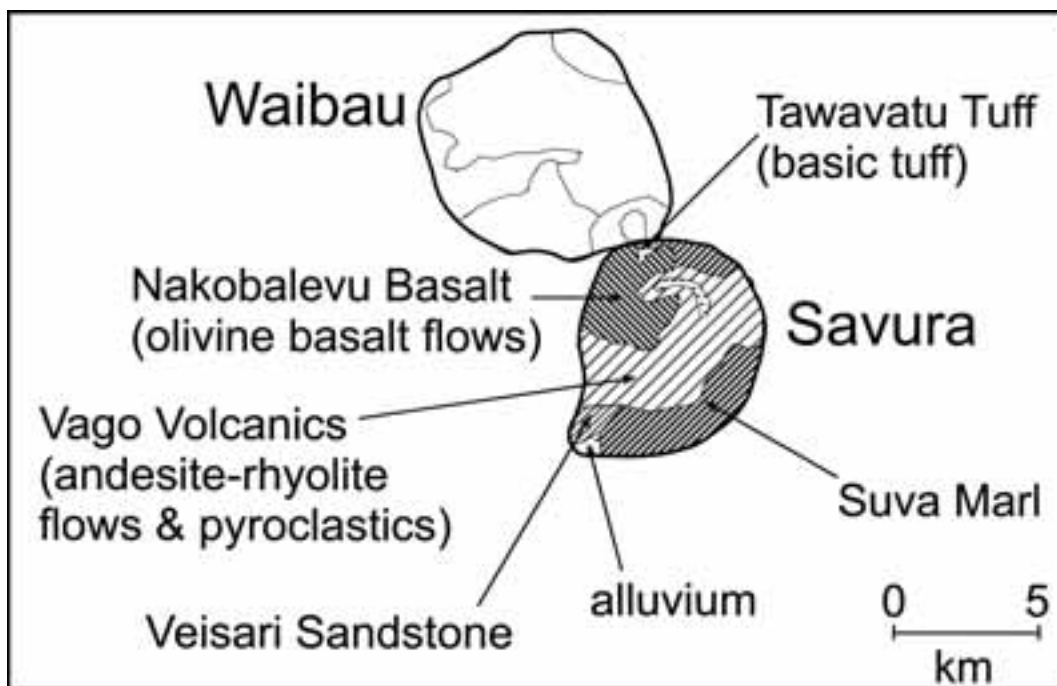


FIGURE 9. The geology of the Savura study area (see text for details).

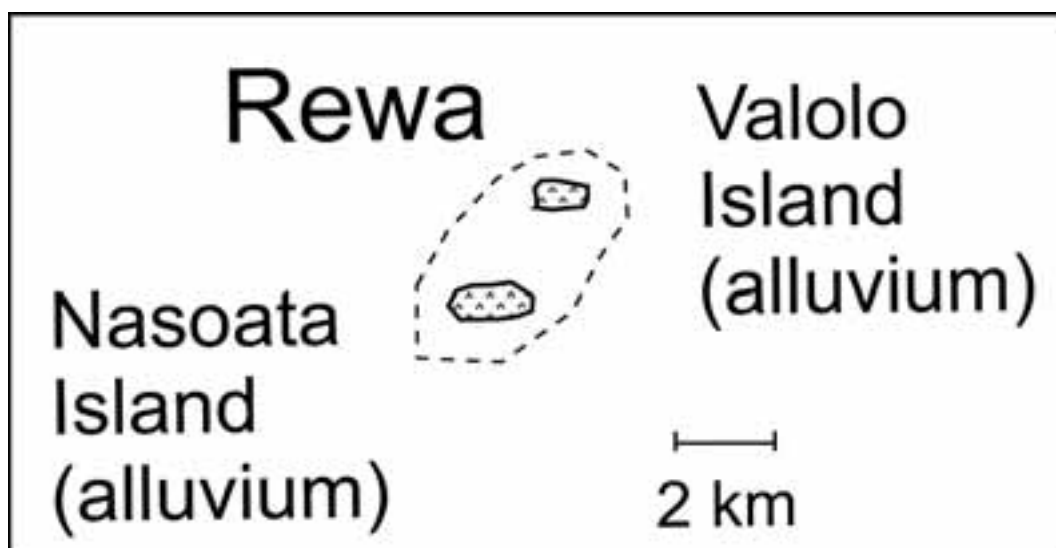


FIGURE 10. The geology of the Rewa study area (see text for details). All the lithology shown is undifferentiated alluvium and marine-derived sediments.

and in fact some of the coastal ranges are known to be drier than the coasts.

The southeast part of the PABITRA Gateway Transect (including the study areas of Waibau, Savura, and Rewa) is represented by climate stations at Laucala Bay (in Suva) and Nausori Airport (at the head of the Rewa Delta). These are illustrated in Figure 11B and 11D, respectively. Both have 22 yr of data. Mean annual temperatures are 25.8°C at Laucala Bay and 25°C at Nausori Airport. These warmer temperatures are typical of locations (unlike Navua: see preceding discussion) that are less often covered by orographic clouds. It is common on a sunny afternoon in Suva to observe the rain clouds massing on the slopes northwest of the city. The mean annual precipitation levels of 2,859 mm at Laucala Bay and 2,759 mm at Nausori Airport are typical of such locations. Most rain is orographic but supplemented by convectional rain, often accompanied by awesome electric storms on still days. The inland study areas of Waibau and Savura probably have slightly cooler average temperatures and slightly greater average rainfalls than

these two stations. The Rewa study area is closest to the Nausori Airport station.

GROSS EFFECTS OF GEOLOGY AND CLIMATE ON VEGETATION

The natural vegetation patterns of Viti Levu are probably closely related to the island's geology and climate. Of the two factors, climate is most important in the gross sense. Most of the windward side of the island, which includes most of the PABITRA Gateway Transect, is covered by rain forest, characteristic of the area's humid tropical climate. In this relatively warm environment the most important climate characteristic affecting vegetation patterns is precipitation. In years when rainfall is well below average, main rain-forest species become noticeably stressed, and more drought-tolerant species can make inroads into areas where they were not known before. Conversely, intense and prolonged rainfall can destabilize the land surface, sometimes leading to the uprooting of old trees and the subsequent recolonization of such areas by alien species.

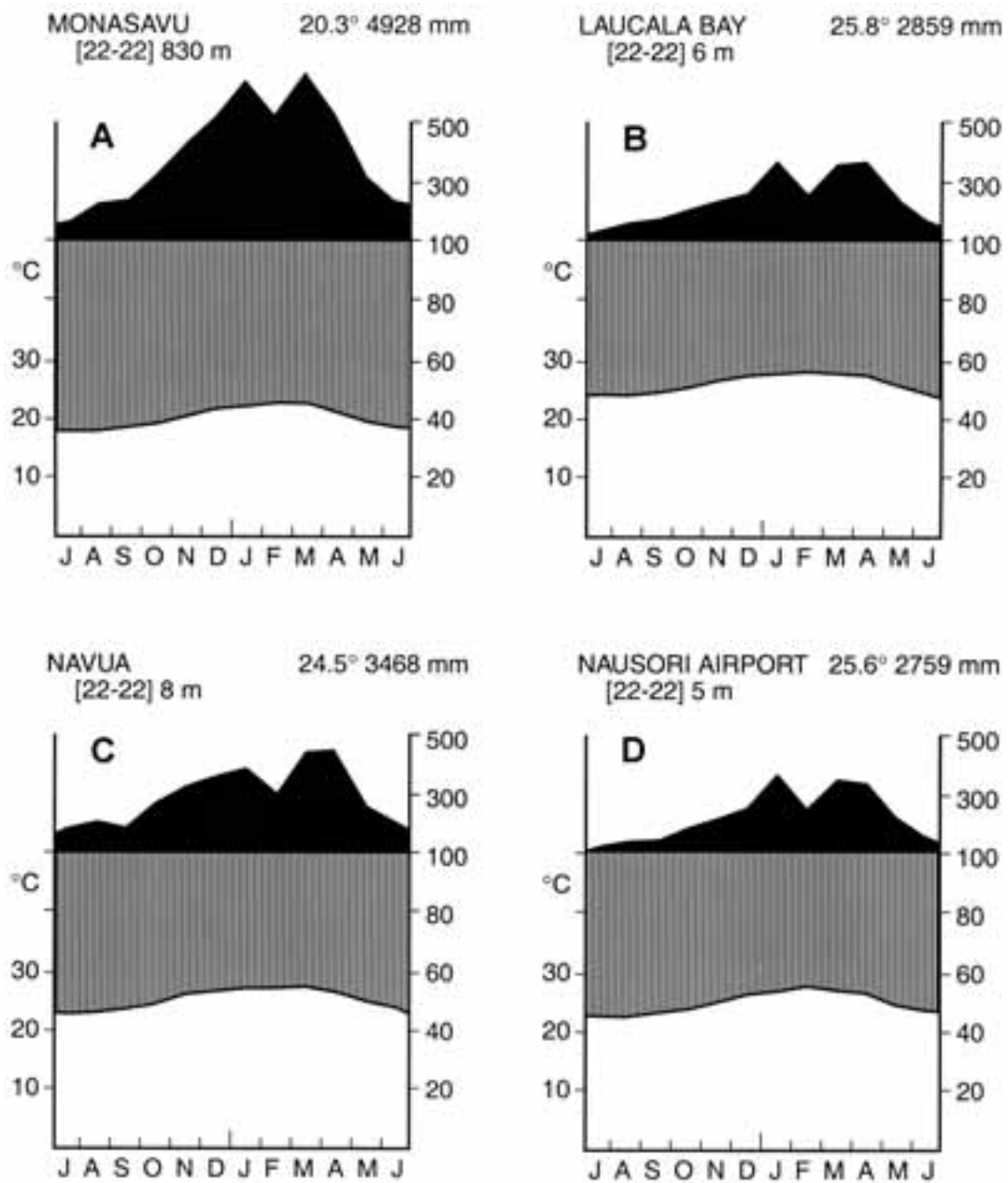


FIGURE 11. Climate diagrams within or adjacent to the PABITRA Gateway Transect: *A*, Monasavu; *B*, Laucala Bay; *C*, Navua; *D*, Nausori Airport. The diagrams were produced following the method of Walter et al. (1975). See Figure 3 for station locations.

Geology also has an important influence on vegetation patterns. Of all the geologic factors, lithology (rock type) seems most important. Different assemblages of forest trees and shrubs typically exist on intrusive compared with extrusive (volcanic) igneous rocks, and areas of limestone can commonly be recognized from afar by their dense forest cover. Structure and tectonics are also important elements of geology that control vegetation in the sense that they explain the areas of greater and lesser amounts of vegetation. The interior parts of Viti Levu, for example, are believed to be rising and this has contributed to its comparatively high altitude and its distinctive cloud forest.

LANDSCAPES OF VITI LEVU ISLAND

Geology and climate are also the principal controls on the landscape of Viti Levu. Lithology controls much of the topography, through the differential erodibility of particular rock types. For example, outcrops of tonalite and diorite in the Colo Plutonics are highly resistant to erosion and typically stand out within the landscape. Sedimentary rocks that are poorly or partly lithified are, in contrast, easily erodible and typically form valley areas. But tectonics and structure are also important controls on landscape in the PABITRA Gateway Transect. The main valley of the Wainimala below Laselevu follows major structural lines, but the valley above Laselevu is a classic example of a deeply incised, meandering river, the product of several hundred meters of uplift (Nunn 1998).

The physical landscape of the windward (wet) side of Viti Levu contrasts in many ways with that of the leeward (dry) side (Nunn 1998), but only a few of the differences are readily explicable by climatic factors. One of the least controversial is the effect of tropical cyclones, particularly in eroding the landscape of its mantle of regolith on the windward side of Viti Levu. Another is the fluvial landscape of many rivers in the PABITRA Gateway Transect compared with those of the leeward side; such rivers tend to be more active and develop altogether more

complex fluvial geomorphologies where discharges are higher and more variable.

CONCLUSIONS

This paper may give the impression that a satisfactory amount is known about the geology, climate, and landscape of the PABITRA Gateway Transect on Viti Levu Island in Fiji. Nevertheless, there is manifestly more to be done. Part of the problem lies in the fact that much of the area remains covered in rain forest. Exposures of the underlying rocks, although increasing with every new roadcut, are still insufficient to give as much information as needed to understand the geology and geologic evolution as completely as desirable. It is hoped that a continuing interest in the biogeography and biodiversity of the Fiji PABITRA Gateway Transect will be accompanied by an ongoing interest in understanding its geology.

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